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ORIGINAL RESEARCH

LEG-LENGTH INEQUALITY AND RUNNING-RELATED INJURY AMONG HIGH SCHOOL RUNNERS

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ABSTRACT

Background: Participation in high school cross-country continues to increase with over 492,000 participants during the 2016-17 cross-country season. Several studies have indicated a high incidence of running-related injuries (RRI) in high school cross-country runners. Risk factors for RRI can be divided between intrinsic and extrinsic risk factors. Intrinsic risk factors such as structural asymmetries have received less attention in recent years.

Purpose: The primary purposes of the current study were to (1) describe the prevalence of leg-length inequality among female and male high school cross-country runners, and (2) to determine whether leg-length inequality was associated with increased RRI in female and male high school cross-country runners.

Study Design: Prospective observational cohort study.

Methods: Three hundred ninety-three (222 males, 171 females) athletes competing in high school cross-country running were followed, prospectively. The runners' right and left leg-lengths were measured with a standard cloth tape measure in a supine position. Incidence of low back/lower extremity RRI during practices or competitive events was monitored using the Daily Injury Report.

Results: A similar percentage of leg-length inequality greater than 0.5 cm was found among female (19.3%) and male (22.1%) runners. No statistically significant associations were found between leg-length inequality and (RRI) for female or male runners, with the exception that after adjusting for BMI, males with a leg-length inequality $>$1.5 cm were over seven times more likely to incur a lower leg RRI (Adjusted Odds Ratio = 7.47; 95%CI: 1.5, 36.9; p = 0.01) than males with a leg-length inequality $\leq$0.5 cm. Side of RRI was not associated with side of longer limb length.

Conclusions: While leg-length inequality was not associated with RRI, in general, males with a leg-length inequality $>$1.5 cm were at greater likelihood of sustaining a lower leg RRI.

Level of Evidence: 2b

Keywords: Asymmetry, Leg-length, High school, Cross-country running, Prospective, Running-related injury

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INTRODUCTION

Running continues to be a popular sport. According to RunningUSA, the number of running event finishers in the U.S. increased from an estimated 4,797,000 in 1990 to 17,114,800 in 2015.[1] However, running has a relatively high incidence of lower extremity injury, with the incidence ranging from 17.9-79.3% based on the study design.[2] Thus, understanding the relationship of factors related to the etiology of running-related injury (RRI) is an important focus of running research.

There is running-related literature that suggest that extremes of anatomic variation and malalignment may predispose runners and military populations engaged in running-related activities to musculoskeletal overuse injury.[3-10] Of these, increased navicular drop[5-7] and large quadriceps angle ([Q-angle] the angle formed between lines from the anterior superior iliac spine to the center of the patella, and from the center of the patella to the center of the tibial tubercle) or greater right-left Q-angle difference[8-10] have gained support as risk factors. The literature regarding leg-length inequality as a risk factor for RRI is equivocal in adult competitive and recreational runners[11-21] and military training populations.[8,10,22] Several factors may contribute to the mixed results including differing study designs and measurement techniques, which do not allow direct comparisons among studies.[8,10-22] Further, there is no consensus on a criterion that distinguishes a normal from an abnormal leg-length inequality.[23]

Over 492,000 female and male athletes participated in cross-country running in the United States during the 2016-2017 high school season.[24] Recent studies of high school runners have indicated that the incidence of RRI ranges from 33% to 47% per season.[25-28] Presently, there are no published prospective cohort reports that have provided an in-depth analysis on the relationship between leg-length inequality and RRI among high school runners. The author has previously reported on several risk factors in a large prospective observational cohort study.[27] In this previous study, data was collected on leg-length but was not reported in-depth. Thus, the primary purposes of the current study were to (1) describe the prevalence of leg-length inequality among female and male high school cross-country runners, and (2) to determine whether leg-length inequality was associated with increased RRI in female and male high school cross-country runners. Additionally, as the evidence for whether side of inequality is related to injury is mixed in adult running or military populations,[17,18,29-35] side of inequality was examined to determine if the shorter or longer leg limb was associated with side of running-related injury in female and male high school cross-country. Further, as body mass index has been associated with RRI,[36,37] particularly lower leg RRI,[38-40] its influence on the relationship between leg-length inequality and RRI was assessed.

METHODS

Setting & Sample

The study prospectively followed 12 Washington State high school cross-country teams during a high school cross-country season. Four hundred twenty-one runners (186 females, 235 males), who competed on their teams during the high school cross-country season and were free of symptoms from any RRI at the time of the measurements, participated in the study. The study was approved by The University of Washington Human Subjects Division and the Seattle High School District. Parental consent and athlete assent was obtained for each subject prior to the baseline measurements. During the course of the season, 28 runners (15 females, 13 males) did not finish the season due to noninjury (i.e., stopped competing, dismissed from team). Thus, complete data for 393 runners (171 females, 222 males) were used in the final study analysis.

Data Collection

Leg-Length. Just prior to the season, the main investigator went to each high school at a scheduled meeting time and place to measure their school's runners' leg-lengths. The leg-length of both lower extremities for all runners were assessed with the subject in the supine position where each runner's absolute leg-length was measured with a cloth tape measure from the anterior superior iliac spine to the medial malleolus and recorded in centimeters.[41]

Pilot Reliability Study. At a summer running camp prior to the season, the intrarater reliability for the leg-length measurements was established using a convenience sample of 20 high school runners (10 females, 10 males; n = 40 limbs). The intrarater intraclass correlation coefficient (ICC 3,1) and standard error of measurement (SEM) value for the main investigator was 0.99 (1.05), and was similar for right and left limb lengths, indicating strong reliability and limited measurement error.

Questionnaire. At the time of the leg-length measurements, all subjects completed a questionnaire on baseline characteristics, which asked them to report their sex, age, height and weight.

***Running-Related Injury (RRI)*.** Prior to the season, the research team educated the runners to report any RRI symptoms to their coach. Additionally, each coach was trained in how to recognize common RRI symptoms among their runners and how to properly record them in the daily injury report (DIR) form.[26,27] A RRI was defined as any reported muscle, joint, or bone problem/RRI of the low back or lower extremity (i.e., hip, thigh, knee, shin, calf, ankle, foot) resulting from running in a practice or meet that required the runner to be removed from a practice or competitive event or to miss a subsequent practice or competitive event.[26,27] A day lost to RRI was any day in which the runner was not able or permitted to participate in an unrestricted manner.[26,27] For each RRI, the coaches recorded the body location and side injured.

DATA ANALYSIS

Mean and standard deviations for age, height, weight, body mass index (BMI), and leg-length were calculated by gender to document the runner's personal characteristics. Statistical comparisons of baseline characteristics by gender were performed with the Student *t* test.[42] The likelihood of a RRI by leg-length inequality was analyzed in four ordered categories ($\leq$0.5cm, >0.5 cm to $\leq$1.0 cm, >1.0 cm to $\leq$1.5 cm, >1.5 cm) to evaluate a possible graded dose-response effect, using the leg-length $\leq$0.5cm as the reference group. This latter group was chosen as the referent category because leg-length inequality in this range have been suggested as normal.[8,10,18] Only the runner's initial RRI was used in all data analyses. Univariate odds ratios (ORs) with 95% confidence intervals (CIs) were used to compare initial RRI risks at different levels of leg-length inequality, comparing the cumulative incidence in an exposed group (>0.5 cm to $\leq$1.0 cm, >1.0 cm to $\leq$1.5 cm, or >1.5 cm), divided by the cumulative incidence in the baseline or referent group ($\leq$0.5cm). ORs and 95% CIs were also computed to assess whether side of RRI was associated with the side of longer leg-length. Univariate ORs and 95% CIs were then calculated to determine if RRI to specific lower extremity body parts were associated with leg-length inequality.[42,43] Finally, multivariable logistic regression was used to calculate the adjusted ORs (AORs) and 95% CIs to assess the effect of body mass index (BMI) a potential confounding factor on the association between leg-length inequality and increased likelihood of RRI.[7,36-40] An alpha level of 0.05 was used for all statistical analyses. All data were analyzed with SPSS (IBM Statistics SPSS 22.0, Armonk, NY).

RESULTS

Participants

Selected baseline characteristics of the 393 runners are presented in Table 1. Females and males were similar in age ($p = 0.82$) (Table 1). While females were lighter and shorter than males, no significant differences were found in regards to BMI ($p = 0.34$).

On average, females had significantly shorter (mean $\pm$ SD) right (87.38 cm $\pm$ 4.34) and left (87.39 cm $\pm$ 4.31) leg-lengths than males (92.98 cm $\pm$ 4.39 and 93.10 cm $\pm$ 4.42, respectively) ($p < 0.0001$). The mean difference between right and left leg-lengths for females (0.34 cm $\pm$ 0.51) was not significantly different from the right and left leg-length mean difference for males (0.37 cm $\pm$ 0.57) ($p = 0.66$). Females

Table 1. *Baseline characteristics of high school cross-country runners (N = 393).*

	Girls (N=171)		Boys (N=222)	
Characteristic	Mean	SD	Mean	SD
Age (y)	15.6	1.1	15.6	1.2
Height (cm)	165.8	6.8	175.5	7.7
Weight (kg)	56.3	6.3	62.7	8.8
Body Mass Index (kg/m^2)	20.5	1.9	20.3	2.1
Right leg-length (cm)	87.38	4.34	92.98	4.39
Left leg-length (cm)	87.39	4.31	93.10	4.42
Right-Left leg-length inequality (cm)	0.34	0.51	0.37	0.52

SD, Standard deviation.

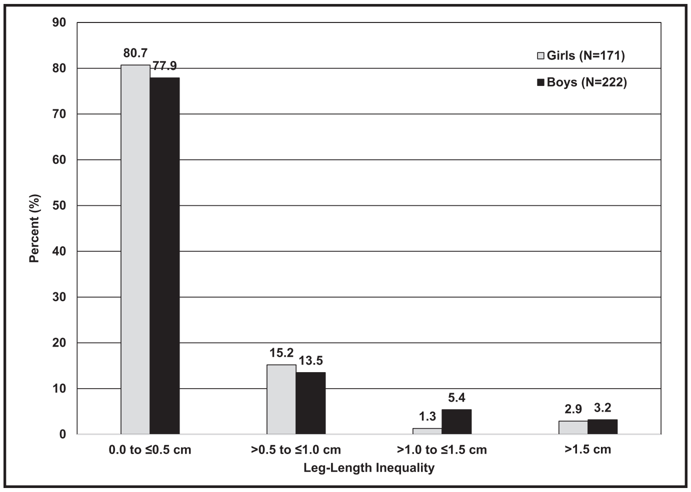

Figure 1. *Distribution of leg-length asymmetry among high school cross-country runners (N = 393).*

(19.3%) and males (22.1%) had a similar percentage of leg-length inequality greater than 0.5 cm (Figure 1). Only one runner, a female, had a leg-length inequality value (2.5 cm) that exceeded 2.0 cm.

RRI Incidence

While 69 (40.4%) of the 171 female runners sustained at least one RRI, 79 (35.6%) of the 222 male runners experienced at least one RRI during the high school season. For females, the shin (42%) was the most common RRI site, followed by the knee (23%), hip (12%), and ankle (10%). For males, the knee (30%) was the body location most commonly injured, followed by the shin (22%) and ankle (13%).

Likelihood of RRI by Leg-length Inequality

Unadjusted and adjusted likelihood estimates of RRI in relation to leg-length inequality for females and males are presented in Table 2. For females and males, no statistically significant association was found between leg-length inequality and RRI. Similarly, when adjusted for BMI, no statistically significant relationships between leg-length inequality and RRI were found.

Side of RRI by Limb Side

While a slightly higher percentage of RRI occurred on the side of RRI on the limb with the greater leg-length (>0.5 cm) for males, the association was not statistically significant ($p = 0.68$) (Table 3). Similarly, no association was found between side of RRI and longer limb side (>0.5 cm) for females ($p = 0.57$). The relationship between leg-length inequality and body location injured is presented in Table 4.

Likelihood of Injured Body Location by Leg-length Inequality

After adjusting for BMI, males with a leg-length inequality >1.5 cm were over seven times more likely to incur a lower leg (shin/calf) RRI (AOR

Table 2. *Unadjusted and adjusted relationships between all RRIs and leg-length inequality among high school cross-country runners (N = 393).*

Leg-length Inequality	N*	Injured N	Injured (%)	OR	95% CI	AOR†	95% CI
Girls							
0.0 to ≤0.5	138	54	(39.1)	1.0 (ref)		1.0 (ref)	
>0.5 to ≤1.0	26	10	(38.5)	0.97	0.4-2.3	0.92	0.4-2.2
>1.0 to ≤1.5	2	2	(100.0)	0.00	NA	0.00	NA
>1.5	5	3	(60.0)	2.33	0.4-14.4	2.07	0.3-13.1
Boys							
0.0 to ≤0.5	173	59	(34.1)	1.0 (ref)		1.0 (ref)	
>0.5 to ≤1.0	30	9	(30.0)	0.82	0.4-1.9	0.86	0.4-2.0
>1.0 to ≤1.5	12	7	(58.3)	2.71	0.8-8.9	2.72	0.8-9.0
>1.5	7	4	(57.1)	2.58	0.6-11.9	2.48	0.5-11.5

N*, Number at risk for running-related injury; RRI, Running-related injury; OR, Odds Ratio; CI, Confidence Interval; AOR, Adjusted odds ratio; ref=Referent group; NA=Not applicable.
†Adjusted for body mass index

Table 3. *Cumulative incidence of RRI by side of RRI and side of greater-length inequality among high school cross-country runners.*

	Side of RRI						Lower Back Injured		Total Injured
	Right Limb Injured		Left Limb Injured		Bilateral Limbs Injured				
Side of Greater Inequality (cm)	N*	(%)	N*	(%)	N*	(%)	N*	(%)	N*
Girls									
Right limb >0.5 than left limb	1	(4.5)	2	(13.3)	2	(6.7)	0	(0.0)	5
Right ≤0.5 to Left ≤0.5	20	(91.0)	10	(66.7)	22	(73.3)	2	(100.0)	54
Left limb >0.5 than right limb	1	(4.5)	3	(20.0)	6	(20.0)	0	(0.0)	10
Boys									
Right limb >0.5 than left limb	5	(15.6)	2	(10.0)	3	(12.5)	0	(0.0)	10
Right ≤0.5 to Left ≤0.5	25	(78.1)	15	(75.0)	16	(66.7)	3	(100.0)	59
Left limb >0.5 than right limb	2	(6.3)	3	(15.0)	5	(20.8)	0	(0.0)	10

*Number injured; RRI, running-related injury.

=7.47, 95% CI: 1.5, 36.9; p=0.01) than males with a leg-length inequality ≤0.5 cm. No statistically significant associations were found between leg-length inequality at other body locations for males or for females at any body location.

DISCUSSION

The findings of this study suggest that most female and male cross-country runners had symmetric right and left leg-lengths. While leg-length inequality was not associated with RRI, in general, males with a leg-length inequality >1.5 cm were at greater likelihood of sustaining a lower leg RRI. Finally, a larger leg-length inequality was not related to side of injured limb for female or male runners.

Despite the use of leg-length inequality as a measure of structural abnormality to predict injuries in running and military populations, few studies have provided the prevalence of clinically-measured leg-length inequality data.[8,10,12,18] Furthermore, the difficulty in comparing the prevalence of leg-length inequality is that there is no widely accepted criterion value for what constitutes a large or excessive leg-length inequality for males or females, especially for adolescent runners. The criterion values reported in prior running and other athletic and military studies has varied from leg-length inequality of 0.5 cm to >2.54 cm (>1.0 inch).[8,10,12,18] Consistent with prior reports, few runners in this study had a leg-length inequality that would be considered excessive. Approximately 80% of the runners had a leg-length inequality less than 0.5 cm with a slightly higher prevalence of leg-length inequality i.e., >0.5 cm, among the boy runners. Overall, using Reid and Smith's classification of bilateral discrepancy,[44] all the runners' leg-length discrepancies would have been considered mild (i.e., inequalities less than 3 cm).

Consistent with prior studies,[8,12,21] this study did not find a statistically significant relationship between leg-length inequality and overall RRI for high school cross-country runners. Noteworthy though was that for female and male runners, the findings suggested a pattern toward greater risk of RRI as the leg-length inequality increased. The non-statistically significant risk estimates may be partially due to the smaller number of runners with greater leg-length inequalities >1.0 cm. Different measurement techniques have been used to examine the relationship between leg-length inequality and RRI. Only two studies were appropriate for direct comparison using the same measurement technique and criterions in this study,[10,18] with the findings in this study consistent with those reported by Rauh et al[10] but differing from those observed by Bennell et al.[18] Comparisons with other studies that used the same measurement technique but did not specify a criterion were also equivocal.[11,14,15,17,19,20] The mixed findings indicate that further study is needed to determine if there is a more sensitive measurement technique or criterion, or both, that might be more valid to evaluate the risk relationship between leg-length inequality and RRI.

Several authors have reported associations between leg-length inequality and specific body locations (i.e., low back injury,[19] ankle injury[19]) or injury type

Table 4. *Relationship between body location injured by leg-length difference among high school cross-country runners (N = 393).*

Leg length inequality	N*	Lower Back Injured N	(%)	AOR	95%CI	Hip/Thigh Injured N	(%)	AOR	95%CI	Knee Injured N	(%)	AOR	95%CI	Lower Leg Injured N	(%)	AOR	95%CI	Ankle/Foot Injured N	(%)	AOR	95%CI
Girls																					
0.0 to ≤0.5	138	2	(1.5)	1.0 (ref)		10	(7.2)	1.0 (ref)		11	(8.0)	1.0 (ref)		23	(16.7)	1.0 (ref)		8	(5.8)	1.0 (ref)	
>0.5 to ≤1.0	26	0	(0.0)	0.00	NA	0	(0.0)	0.00	NA	4	(15.4)	2.23	0.6-7.7	4	(15.4)	0.83	0.3-2.7	2	(7.7)	1.36	0.3-6.9
>1.0 to ≤1.5	2	0	(0.0)	0.00	NA	1	(50.0)	12.10	0.7-211.9	0	(0.0)	0.00	NA	1	(50.0)	4.38	0.3-75.6	0	(0.0)	0.00	NA
>1.5	5	0	(0.0)	0.00	NA	0	(0.0)	0.00	NA	0	(0.0)	0.00	NA	2	(40.0)	2.67	0.4-17.7	1	(20.0)	4.06	0.4-40.7
Boys																					
0.0 to ≤0.5	173	3	(1.7)	1.0 (ref)	NA	11	(6.4)	1.0 (ref)		18	(10.4)	1.0 (ref)		15	(8.7)	1.0 (ref)		12	(6.9)	1.0 (ref)	
>0.5 to ≤1.0	30	0	(0.0)	0.00	NA	1	(3.3)	0.48	0.1-3.9	2	(6.7)	0.65	0.1-3.0	3	(10.0)	1.27	0.3-4.8	3	(10.0)	1.51	0.4-5.8
>1.0 to ≤1.5	12	0	(0.0)	0.00	NA	2	(16.7)	2.95	0.6-15.2	2	(16.7)	1.71	0.3-8.5	3	(25.0)	3.52	0.8-14.8	0	(0.0)	0.00	NA
>1.5	7	0	(0.0)	0.00	NA	0	(0.0)	0.00	NA	0	(0.0)	0.00	NA	3	(42.9)	**7.47**	**1.5-36.9**	1	(14.3)	2.20	0.3-19.9

N*, Number at risk for running-related injury; AOR, Adjusted Odds Ratio; CI, Confidence Interval; Ref, Reference group: NA, Not applicable.

(stress fracture,[18] plantar fasciitis[14,15]). In the current study, of the five body locations examined, only the lower leg, (shin/calf) was found to be associated with RRI among male runners with a leg-length inequality >1.5 cm. This finding differentiates from other studies that examined leg-length inequality and lower leg pain and found no significant relationship.[10,12,17] It is possible that these previously cited reports did not find a relationship due to cross-sectional design,[12,17] smaller samples,[12,17] and populations studied (adult runners[12,17], female recruits[10]). Even though the relationship between leg-length inequality and lower leg RRI was strengthened as the association remained significant after adjusting for body mass index, some caution is advised when interpreting the statistical (95% confidence interval was fairly wide indicating limited precision of the association) and clinical significance of this finding as they are based on only seven male runners who had a leg-length inequality of >1.5 cm, of which three had a lower leg RRI. Still, the finding provides some support that greater malalignment of the lower extremities may increase the odds of a male high school runner incurring a RRI.

The evidence regarding whether the longer limb or shorter limb is at greater risk of RRI appears equivocal and has been primarily examined in adult running or military populations. While several authors have reported the longer limb had a higher occurrence of RRI,[29-33] others have indicated that the shorter limb was at more risk,[33,34] and others no association.[18,35] The results of the current study indicate that the RRI did not always occur on the limb with the larger limb length. A possible reason why a side difference may not have been observed is that the cutpoint used may have been more conservative than prior studies. Additionally, including a bilateral limb injured group may have affected the ability to observe a right or left side greater side difference as over one-third (n = 54) of the RRI were considered bilateral.

Several limitations of this study are noteworthy. The RRI collected in this study was based on a) self-reported RRI symptoms from the runners to the coaches or b) direct observation by the coaches if they suspected that a runner was experiencing a RRI symptom. The use of self-reported RRI data is a potential limitation as it may have resulted in an underreporting of RRI, possibly due to some runners feeling that their pain symptoms were not severe enough to report and continued running through the RRI and/or feared that they would be restricted from a practice or competitive event. Second, some coaches may not have reported all RRI into the DIR. However, coaches were trained in how to complete the DIRs and were contacted on a weekly basis to minimize underreporting. Thus, there was increased confidence that the coaches' reporting of RRI events were reasonably reliable and accurate due to the training they received to recognize and report RRI.[26,27,45]

Several strengths of this study are also of note. This study found that leg-length measures for both limbs could be measured quickly and reliably on adolescent runners of both genders. The prospective design allowed the leg-length status of each runner to be established before RRI occurred, decreasing the likelihood of recall or measurement bias.[42,46]

Recommendations for Future Research

Further investigation into the relationship between running-related RRI and leg-length inequality is recommended, particularly prospective studies with larger male and female adolescent cohort sizes. This will increase the ability to better examine the effects on leg-length inequality and specific body locations by gender. It is also recommended that leg-length inequality data be grouped according to measured values so that the findings are more transferable for clinical interpretation.[9,47] Finally, although preventive interventions using heel pad/lift or orthotics to correct leg-length inequality are commonly used, recent evidence examining their protective effectiveness in minimizing injury in running and other sport populations appears equivocal.[48-53] While this particular study did not address whether heel pad/lift or orthotic use played a protective effect in RRI among high school runners with leg-length inequality, it still behooves future prospective studies to determine their role as an injury prevention measure.

CONCLUSION

The results of this prospective study of high school female and male cross-country runners indicate that leg-length inequality was not associated with RRI, with the exception that males with a leg-length inequality >1.5 cm were at greater likelihood of incurring a lower leg (shin/calf) RRI. Further, the shorter or longer limb was not associated with side of RRI. Given the lack of association between the injured side and the side of the leg-length inequality in this study, clinicians should give equal consideration to the long or short limb when evaluating the injuries of high school runners.

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